

SAGA-HE-157-00

January 4, 2000

Flavor asymmetry in polarized proton-deuteron Drell-Yan process

S. Kumano *

Department of Physics
Saga University
Saga 840-8502, Japan

Talk at the RCNP-TMU Symposium on
“Spins in Nuclear and Hadronic Reactions”

Tokyo, Japan, October 26 - 28, 1999
(talk on Oct. 28, 1999)

* Email: kumanos@cc.saga-u.ac.jp. Information on his research is available at <http://www-hs.phys.saga-u.ac.jp>.

to be published in proceedings

Flavor asymmetry in polarized proton-deuteron Drell-Yan process

S. Kumano

Department of Physics, Saga University

Saga 840-8502, Japan

E-mail: kumanos@cc.saga-u.ac.jp

We discuss the possibility of finding polarized antiquark flavor asymmetry in Drell-Yan processes. We find that the difference between polarized proton-proton and proton-deuteron Drell-Yan cross sections should provide valuable information on the polarized flavor asymmetry. Numerical results indicate that the asymmetry effects are conspicuous especially in the large- x_F region. Our analysis is important for the transversity distributions because the flavor asymmetry cannot be found by inclusive lepton scattering and W-production processes.

1 Introduction

Antiquark distributions used to be considered flavor symmetric for the light antiquark distributions ($\bar{u} = \bar{d}$). However, it became apparent that they are significantly different¹ because of the experimental findings of Gottfried-sum-rule violation and proton-deuteron asymmetry in Drell-Yan experiments. Although meson-cloud-type models seem to be the promising explanation, various models have been proposed to explain the experimental data. In order to test the theoretical ideas, we need further experimental information. In particular, polarized flavor asymmetries should provide crucial information for determining the physics mechanism behind the flavor asymmetric distributions.

Longitudinally-polarized parton distributions have been investigated mainly through the structure functions g_1 for the proton, neutron (or ${}^3\text{He}$), and deuteron.² Semi-inclusive data were also obtained; however, they are not accurate enough at this stage to provide any significant constraint on the polarized distributions.³ Therefore, the antiquark distributions are assumed to be flavor symmetric in almost all the parametrizations.² We expect that the situation will become clearer by the RHIC-Spin and other experiments. As far as the transversity is concerned, there is no experimental information yet. Although experiments could be done at RHIC and HERA, nobody knew how to measure the light-antiquark flavor asymmetry because the transversity distributions cannot be measured in the inclusive lepton scattering and W-production experiments due to the chiral-odd property. Reference 4 proposed that the polarized proton-deuteron (pd) Drell-Yan process could be used in combination with the proton-proton (pp) Drell-Yan for extracting the flavor asymmetry information. We discuss such possibility in this talk.

In Sec. 2, relations between the polarized pd Drell-Yan process and the polarized parton distributions are introduced. Then, we discuss how to extract the light antiquark distributions from the polarized pd Drell-Yan cross section in Sec. 3. Our studies are summarized in Sec. 4.

2 Proton-deuteron Drell-Yan process

Unpolarized Drell-Yan processes have been studied as an alternative method to lepton scattering for finding parton distributions in the nucleon and nuclei. The unpolarized and polarized pp Drell-Yan processes have been investigated theoretically for a long time. In addition, the unpolarized pd Drell-Yan is used experimentally for extracting the flavor-asymmetry information (\bar{u}/\bar{d}) . If the proton and deuteron are polarized in the pd Drell-Yan process, we could investigate a polarized version of the flavor asymmetry. This topic is discussed in Sec. 3. However, it is not straightforward to express the pd cross section in terms of structure functions. In particular, it was not clear how the tensor structure is involved in the polarized cross section. Reference 5 clarified this point.

In formulating the polarized pd Drell-Yan, we tried two different methods.⁵ The first one uses the Jacobi-Wick helicity formalism with the spin-density matrices. The essential difference from the pp reaction is that there exist rank-two tensors due to the spin-1 nature of the deuteron. The conditions of Hermiticity, parity conservation, and time-reversal invariance are imposed on possible structure functions. Then, we found that there are 108 structure functions in general. If they are integrated over the virtual-photon transverse momentum \vec{Q}_T , there exist only 22 structure functions. In the second method, the hadron tensor is expressed in terms of possible combinations of momentum and spin vectors by imposing the same three conditions. Only the limiting case $Q_T \rightarrow 0$ is considered in this analysis, and we also obtained the same 22 structure functions. These finite functions should be physically significant ones which could be investigated by the polarized pd Drell-Yan process.

Considering the present situation on the proton spin physics, we think that the 22 functions are still too many to be investigated seriously. Furthermore, the physics meaning of these functions, particularly the new ones which do not exist in the pp reaction, is not clear. Therefore, the pd Drell-Yan was also analyzed in a parton model.⁵ The hadron tensor is expressed by correlation functions for the process $q + \bar{q} \rightarrow \ell^+ + \ell^-$. Then, the correlation functions are expanded in terms of the sixteen 4×4 matrices: $\mathbf{1}$, γ_5 , γ^μ , $\gamma^\mu \gamma_5$, $\sigma^{\mu\nu} \gamma_5$ and kinematical Lorentz vectors and pseudovectors. Then, we found finite structure functions in the parton model. There is a new polarization asymmetry A_{UQ_0}

with the unpolarized proton and the tensor-polarized deuteron. It is given by the parton distributions in the proton and deuteron as

$$A_{UQ_0} = \frac{\sum_a e_a^2 [f_1(x_1) \bar{b}_1(x_2) + \bar{f}_1(x_1) b_1(x_2)]}{\sum_a e_a^2 [f_1(x_1) \bar{f}_1(x_2) + \bar{f}_1(x_1) f_1(x_2)]}, \quad (1)$$

where $f_1(x)$ and $\bar{f}_1(x)$ are unpolarized quark and antiquark distributions, and $b_1(x)$ and $\bar{b}_1(x)$ are tensor-polarized distributions. The b_1 structure function is known in lepton scattering;⁶ however, the Drell-Yan process provides important information on the antiquark tensor polarization \bar{b}_1 . However, this topic is no more discussed in the following because it is not the major purpose of this paper to investigate the tensor structure. We refer the reader to Ref. 5 for more details. In the following, we discuss the double longitudinal and transverse spin asymmetries in connection with the flavor asymmetry.

First, according to the general formalism⁵ the difference between the longitudinally-polarized pd cross sections is given by

$$\Delta\sigma_{pd} = \sigma(\uparrow_L, -1_L) - \sigma(\uparrow_L, +1_L) \propto -\frac{1}{4} \left[2 V_{0,0}^{LL} + \left(\frac{1}{3} - \cos^2\theta \right) V_{2,0}^{LL} \right], \quad (2)$$

where $\sigma(\text{pol}_p, \text{pol}_d)$ indicates the cross section with the proton polarization pol_p and the deuteron one pol_d . The longitudinally polarized structure functions $V_{0,0}^{LL}$ and $V_{2,0}^{LL}$ are defined in Ref. 5. The θ is the polar angle of the lepton ℓ^+ . Then, the structure functions are related to the polarized parton distributions in the parton-model analysis.⁵ The \vec{Q}_T -integrated results indicate

$$\Delta\sigma_{pd} \propto \sum_a e_a^2 [\Delta q_a(x_1) \Delta \bar{q}_a^d(x_2) + \Delta \bar{q}_a(x_1) \Delta q_a^d(x_2)], \quad (3)$$

where Δq_a^d and $\Delta \bar{q}_a^d$ are the longitudinally-polarized quark and antiquark distributions in the deuteron.

In the transverse-polarization asymmetry, the situation is more complicated in the sense that four structure functions ($V_{0,0}^{TT}$, $V_{2,0}^{TT}$, $U_{2,2}^{TT}$, and $U_{2,1}^{UT}$) contribute. However, it becomes a simple expression if the parton model is used by neglecting higher-twist contributions:

$$\begin{aligned} \Delta_T \sigma_{pd} &= \sigma(\phi_p = 0, \phi_d = 0) - \sigma(\phi_p = 0, \phi_d = \pi) \\ &\propto \sum_a e_a^2 [\Delta_T q_a(x_1) \Delta_T \bar{q}_a^d(x_2) + \Delta_T \bar{q}_a(x_1) \Delta_T q_a^d(x_2)], \end{aligned} \quad (4)$$

where $\Delta_T q$ and $\Delta_T \bar{q}$ are quark and antiquark transversity distributions, and ϕ is the azimuthal angle of a polarization vector. In this way, we found that the cross-section difference is written in terms of the longitudinally-polarized and transversity distributions.

3 Light-antiquark flavor asymmetry

Because the expressions of Eqs. (3) and (4) are the same as the unpolarized one if the polarized distributions are replaced by the unpolarized ones, the polarized flavor asymmetries could be extracted from the polarized pp and pd Drell-Yan cross sections as it has been investigated in the unpolarized case. In order to discuss the pp and pd cross sections in connection with the flavor asymmetry, we define the ratio

$$R_{pd} \equiv \frac{\Delta_{(T)}\sigma_{pd}}{2\Delta_{(T)}\sigma_{pp}} = \frac{\sum_a e_a^2 [\Delta_{(T)}q_a(x_1)\Delta_{(T)}\bar{q}_a^d(x_2) + \Delta_{(T)}\bar{q}_a(x_1)\Delta_{(T)}q_a^d(x_2)]}{2\sum_a e_a^2 [\Delta_{(T)}q_a(x_1)\Delta_{(T)}\bar{q}_a(x_2) + \Delta_{(T)}\bar{q}_a(x_1)\Delta_{(T)}q_a(x_2)]}, \quad (5)$$

where $\Delta_{(T)} = \Delta$ or Δ_T depending on the longitudinal or transverse case. There is another issue in calculating the cross sections because of nuclear corrections. However, they are ignored in the following discussions since they are not expected to be the essential part. If experimental data are taken in future, such corrections should be taken into account properly.

We show our numerical-analysis results for the ratio R_{pd} in Fig. 1. The parton distributions are taken from Ref. 7 at $Q^2=1$ GeV 2 , where flavor asymmetry ratio is introduced as $r_{\bar{q}} \equiv \Delta_{(T)}\bar{u}/\Delta_{(T)}\bar{d} = 0.7, 1.0$, or 1.3 . Then, the distributions are evolved to $Q^2 = M_{\mu\mu}=25$ GeV 2 by the leading-order DGLAP evolution equations. The center-of-mass energy is taken as $\sqrt{s}=50$ GeV with a fixed target experiment in mind. In Fig. 1, the solid and dashed curves are longitudinally- and transversely-polarized ratios, respectively. Because the transversity distributions are assumed to be the same as the corresponding longitudinally-polarized ones at $Q^2=1$ GeV 2 , the transverse ratios are almost the same as the longitudinal ones. There are large differences between the curves for $r_{\bar{q}}=0.7, 1.0$, and 1.3 , so that it should be possible to extract the longitudinally-polarized and transversity flavor asymmetries from the ratios $R_{pd}^{(L)}$ and $R_{pd}^{(T)}$. The differences are especially large in the large- x_F region with the following reason. If two extreme limits ($x_F = x_1 - x_2 \rightarrow \pm 1$) are taken in Eq. (1) with the assumption

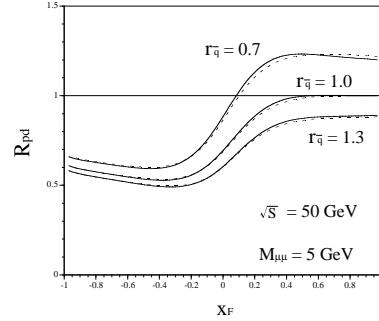


Figure 1: Cross-section ratio R_{pd} (from Ref. 4).

$\Delta_{(T)} u_v(x \rightarrow 1) \gg \Delta_{(T)} d_v(x \rightarrow 1)$, the ratio becomes

$$R_{pd}(x_F \rightarrow +1) = \frac{1}{2} \left[1 + \frac{\Delta_{(T)} \bar{d}(x_2)}{\Delta_{(T)} \bar{u}(x_2)} \right]_{x_2 \rightarrow 0}, \quad (6)$$

$$R_{pd}(x_F \rightarrow -1) = \frac{1}{2} \left[1 + \frac{\Delta_{(T)} \bar{d}(x_1)}{4 \Delta_{(T)} \bar{u}(x_1)} \right]_{x_1 \rightarrow 0}. \quad (7)$$

These equations suggest that the flavor-asymmetric distribution $\Delta_{(T)} \bar{u} - \Delta_{(T)} \bar{d}$ can be extracted by finding the deviation from 1 at $x_F \rightarrow +1$ or from 5/8 at $x_F \rightarrow -1$. However, R_{pd} should be more sensitive to the flavor asymmetry at large x_F due to the factor of 1/4 in Eq. (7) in comparison with Eq. (6).

Next, we show the numerical results in Fig. 2 for larger energies $\sqrt{s}=200$ and 500 GeV by considering a collider option. The solid, dashed, dotted curves are for $\sqrt{s}=50$, 200, and 500 GeV, respectively. Although there are large variations in the medium- x_F region, the ratios in the large- and small- x_F regions stay the same. Furthermore, we studied the parametrization-model dependence,⁴ and the results indicate that the large- and small- x_F ratios are again rather independent of the parametrization. Therefore, these regions are appropriate for investigating the flavor asymmetry. In addition, the variations in the medium- x region indicate that the details of the polarized parton distributions could be investigated in this region.

In this way, we find that it is possible to extract both $\Delta \bar{u}/\Delta \bar{d}$ and $\Delta_T \bar{u}/\Delta_T \bar{d}$ from the cross-section ratios, particularly in the large- x_F region. Our suggestion should be important for the transversity because it cannot be measured in the inclusive lepton scattering and W-production processes.

At this stage, no actual experimental measurement is planned. However, there are certain possibilities at Fermilab, HERA-N, and JHF for measuring the polarized pd Drell-Yan cross sections by using a fixed deuteron target. In addition, the polarized deuteron could be accelerated in principle at RHIC. However, it is not easy to attain the longitudinal polarization due to the small magnetic moment unless someone has a smart idea for the longitudinal polarization.⁸ In any case, we should be able to investigate at least the transverse part at RHIC. As far as the tensor polarization is concerned in Eq. (1), we may combine the transverse cross sections with the unpolarized one

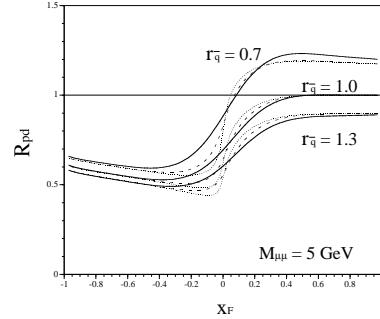


Figure 2: \sqrt{s} dependence (from Ref. 4).

Figure 2: \sqrt{s} dependence (from Ref. 4).

for getting the tensor-polarized cross section. Because there are a variety of interesting topics on polarized deuteron reactions, we hope that experimental possibilities are seriously studied.

4 Summary

First, we briefly discussed the general framework of the polarized pd Drell-Yan process. Then, we explained the relation between the flavor-asymmetry ratio $\Delta_{(T)}\bar{u}/\Delta_{(T)}\bar{d}$ and the Drell-Yan cross-section ratio $\Delta_{(T)}\sigma_{pd}/[2\Delta_{(T)}\sigma_{pp}]$. Our numerical analysis suggested that the polarized flavor asymmetry could be extracted from the pd and pp cross-section measurements particularly in the large- x_F region. At this stage, this is the only proposal for extracting the transversity asymmetry $\Delta_T\bar{u}/\Delta_T\bar{d}$ due to the chiral-odd property.

Acknowledgments

S.K. was partly supported by the Grant-in-Aid for Scientific Research from the Japanese Ministry of Education, Science, and Culture under the contract number 10640277.

References

1. S. Kumano, Phys. Rep. 303 (1998) 183; J.-C. Peng and G. T. Garvey, hep-ph/9912370.
2. Y. Goto, N. Hayashi, M. Hirai, H. Horikawa, S. Kumano, M. Miyama, T. Morii, N. Saito, T.-A. Shibata, E. Taniguchi, and T. Yamanishi (Asymmetry Analysis Collaboration), hep-ph/0001046.
3. T. Morii and T. Yamanishi, hep-ph/9905294; M. Wakamatsu and T. Watabe, hep-ph/9908425.
4. S. Kumano and M. Miyama, hep-ph/9909432, Phys. Lett. B in press.
5. S. Hino and S. Kumano, Phys. Rev. D59 (1999) 094026; Phys. Rev. D60 (1999) 054018.
6. P. Hoodbhoy, R. L. Jaffe, and A. Manohar, Nucl. Phys. B312 (1989) 571; F. E. Close and S. Kumano, Phys. Rev. D42 (1990) 2377.
7. E. Leader, A. V. Sidrov, and D. B. Stamenov, Phys. Lett. B462 (1999) 189.
8. A. Skrinsky, talk at the eRHIC workshop, BNL, USA, Dec. 3-4, 1999.